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A 3-D COUPLED ICE-OCEAN MODEL

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ABSTRACT

A three dimensional ice/ocean model is being developed for ice-forecasting in the Arctic region. Particular emphasis is paid to sea ice distribution and ice edge location. The Hibler dynamic thermodynamic sea ice model is coupled to the Bryan/Cox multilevel baroclinic ocean model.

The coupled model is initially set-up and tested on the Polar Ice Prediction System (PIPS) Arctic grid which has a resolution of 127 km x 127 km (1.14° x 1.14°). This grid is used to test coupling techniques. The model will later be expanded to the PIPS-45 grid. This grid has a resolution of 80 km x 80 km and includes all ice-covered seas from the North Pole to 45° N. The ocean model has 15 vertical levels from the surface to 5700 m. A daily time step is used.

The ice/ocean model is initialized with Levitus seasonal climatology values for temperature and salinity. Fleet Numerical Oceanography Center forcing fields from 1986, which include solar radiation, longwave radiation, and geostrophic winds from surface pressures, are used to force the ice/ocean model.

The coupling is accomplished by using the heat flux, and salt flux, which is determined in the ice model from the growth rate of ice, as surface boundary conditions in the ocean model. The stress on the ocean surface is determined from the wind stress and the internal ice stress. The ocean model is then used to determine the temperature distribution in the ocean and the ocean currents which are feed back into the ice model. The method for coupling is similar to that used by Hibler and Bryan (1987).

The ice/ocean model is integrated forward in time for four years. The results of year four are examined to determine how well the model is simulating ice edge, ice thickness, ocean temperature, etc.

The purpose for the coupling of the PIPS model and the Bryan/Cox ocean model is to improve the forecast capability of the PIPS model. It is hoped that the interaction between an ice and ocean model will yield improved heat and salt fluxes at the ice/ocean interface resulting in improved forecasts of ice edge location and ice thickness distribution.

The PIPS model (Preller, 1985) is based on the Hibler sea ice model (Hibler, 1979 & 1980). The Bryant/Cox ocean model is as described in Bryant (1969). These models will not be described here except to point out that this version of PIPS uses a 7-level ice thickness distribution method after Walsh et. al., 1985. The main discussion will be on the coupling technique used and some results from the coupled model. In this study, river runoff has not yet been included and the ocean tilt $\nabla_H P(0)$ is estimated by the geostrophic approximation. The geostrophic current is assumed to be represented by the ocean current computed at level 2 in the ocean model. Most of the parameters used in the ice/ocean model are unchanged from those used in Hibler and Bryant (1987) and Preller (1985), one change is K_M = 1000 cm^2/sec at level 1 and 10 cm^2/sec at all other levels. These values for K_M were used since the daily winds resulted in instabilities in level 1 ocean currents.

The PIPS grid covers most of the Arctic including the Greenland and Norvegian Seas to the southern coast of Iceland. The vertical grid in the ocean model is the same as used in Hibler and Bryant (1987). Bottom topography was obtained from a Naval Oceanographic Office data base interpolated to the PIPS grid and smoothed with 9-point averaging. The temperature and salinity data was interpolated from Levitus climatology, winter season. The temperature and salinity values at level 10 and below were adjusted by extending the values at level 9 to the bottom by allowing the values to increase very slightly toward the bottom. The ocean model was spun-up for one year to allow the temperature and salinity fields to adjust. This spin-up field was used to initialize the ice/ocean model. The ocean model boundaries are all closed. A relaxation toward climatology for level 2 and below was used as described in Hibler and Bryant (1987) along with a shorter relaxation period at the boundaries of the Greenland Sea and the Bering Strait.

The coupling of the two models is accomplished in such a way as to make the fewest changes in the existing models. The temperature and salinity at level 1 in the ocean model along with the current at level 2 are passed to the ice model. The ice model uses the ocean current in the ice momentum equation. The ocean temperature and salinity at level 1 are used to compute the heat flux from the ocean to the ice. The salinity is used to compute the freezing point of sea water using the relation

$$T_f = -0.0544\ S_1 \qquad (1)$$

where T_f is the freezing point and S_1 is the salinity at level 1. The oceanic heat flux is then computed from

$$F_W = (T_f - T_1)\ C_W\ H_1 / \Delta t \qquad (2)$$

where F_W is the oceanic heat flux, T_1 the temperature at level 1, C_W the volumetric heat of fussion (4.19 MJ $m^{-3}K^{-1}$), H_1 the depth of level 1 in meters, and Δt is the time step. The oceanic heat flux along with the atmospheric forcing is used to compute the growth rate of ice. Then the salt and heat flux from the ice to the ocean can be computed and used as the boundary conditions for the ocean model. For the ice cover case, the salt flux is computed from

$$S_f = (\Delta H_i \ 0.030)/(\Delta t \ H_1) \tag{3}$$

where $\Delta H_i / \Delta t$ is the growth rate of ice and 0.030 is a reference salinity. For the ice free case, the salt flux is presently assumed to be zero. The heat flux for the ice cover case is zero and for the ice free case is actually the total heat content in the first level of the ocean after the net change due to atmospheric forcing is taken into account. The heat flux was set-up this way, since the ice model already keeps track of the heat in a fixed depth mixed layer whenever the grid cell in question is ice free. The above values, S_f and H_f are then passed to the ocean model as boundary conditions. The first level in the ocean model is changed so that a forward time step is used at this level. If ice is present in a grid cell, the temperature at level 1 is set to the freezing point. If there is no ice in the grid cell, the temperature is unchanged. The salinity is updated first using the equation

$$S_1^{n+1} = S_1^n + \Delta S_{adv} + S_f \ \Delta t \tag{4}$$

where ΔS_{adv} is the change in salinity computed by the ocean model due to advection and diffusion (horizontal and vertical). The temperature is updated next using

$$T_1^{n+1} = T_f^{n+1} + \Delta T_{adv} + H_f \ \Delta t \tag{5}$$

where ΔT_{adv} is the temperature change due to advection and diffusion. The temperature is always updated relative to the freezing point whether there is ice cover or open water.

The ice/ocean model was integrated forward in time for four years. Included are plots of the monthly averaged oceanic heat flux (Figure 1) and ice thickness (Figure 2) for a typical winter month (March). The ice edge and ice thickness distribution are reasonable. The ice thickness ranges from 2.0 to 3.0 m in the central Arctic and shows a typical build-up of ice along the Canadian coast. The oceanic heat flux is between 5 and 10 W m^{-2} in the central Arctic. Very large values are observed in the Barents Sea, Greenland Sea and Chukchi Sea. These areas are usually ice free in the summer and the upper layers of the ocean are warmed by solar heating. Some of these areas are also transversed by warm currents. Daily values of oceanic heat flux in these regions may be very large, over 1000 W m^{-2} in spots. In the summer months (not shown), the ice edge retreats to just north of Svalbard and Franz Josef Land in the eastern Arctic and away from the Alaskian and Siberian coast in the western Arctic. The build-up along the Canadian coast still exists, but is slightly thinner. The ice in the central Arctic is 1.2 to 2.2 m thick. Thinner than one would expect for this region. The oceanic heat flux in the summer is from 0.76 to 15 W m^{-2} where there is ice cover. Only in a few places near the ice edge is it greater than 10 W m^{-2}.

The ocean's response to the fluxes is realistic. The temperature at level 1 remains near freezing when there is ice cover. Ice free regions increase in temperature during the summer (max. 11.2 °C) and decrease in the winter (max. 7.0 °C). The salinity decreases under the ice when ice melts (32.0 to 33.6 ppt in central Arctic) and increases when ice freezes (32.8 to 34.4 ppt in central Arctic). There is no salinity variability at the present stage of model development in regions that are ice free all year. Mean ocean currents are reproduced, except that the currents off the coast of Norway are too weak.

The initial results from the coupled ice/ocean model are encouraging. Both the ice and ocean models seem to be responding well to the coupling. There are several areas, however, which must be examined further. The values used in this study for K_M damp the variability of the currents with time too much. Other values should be tried. The values for F_W in the central Arctic during the winter are larger than generally accepted. Why F_W is so large and possible adjustments will be addressed in further development of the model. Also, the ocean currents off the Norwegian coast need to be increased. River runoff should be included along with some salt flux in open water regions. Comparison with available data will also be necessary before expansion of the region to PIPS-45.

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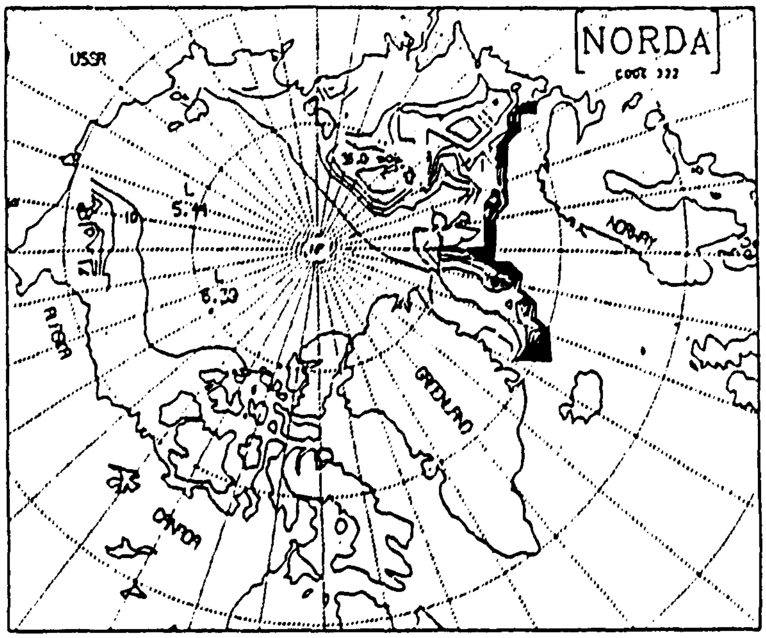
4-11-91

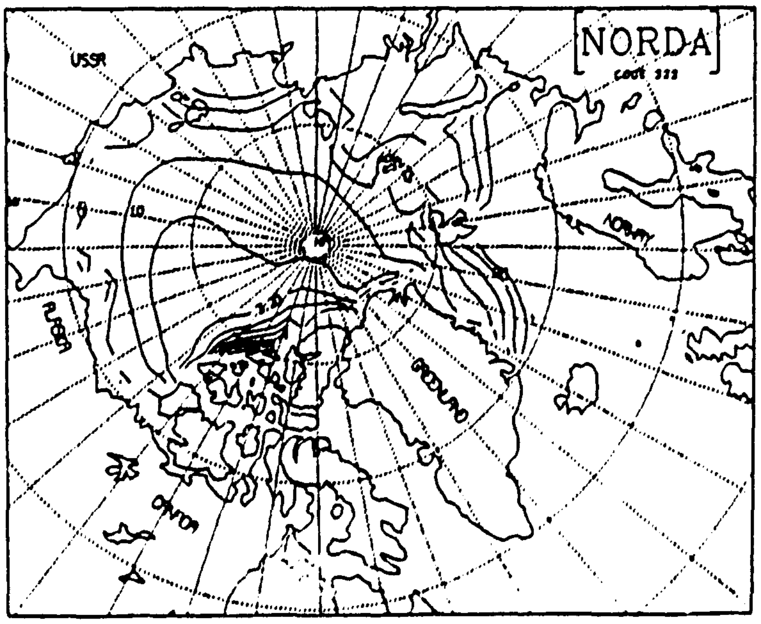
MONTHLY AVERAGE HEAT FLUX - W/M**2 MARCH



ICE-OCEAN MODEL YEAR 4

Figure 1. Monthly averaged oceanic heat flux in W m^{-2} for the month of March from year 4 of the ice/ocean model simulation. (Contour interval 9.0)

MONTHLY AVERAGE ICE THICKNESS - M MARCH



ICE-OCEAN MODEL YEAR 4

... for the month of March